Drying of Fruits, Vegetables, Spices and Medicinal Plants with a Mixed-Mode Solar Drying System with Internal Reflectors

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Abstract
A high moisture content of fresh food products leads to rapid deterioration in the quality of the product because of the growth of micro flora insect infestation etc. It leads to a great loss of farmers. It is a basic fact that the sustainable development of any nation or society depends on a safe, nutritious, dependable, and affordable food supply. There is a way to minimize the food wastage is dehydrating food products up to a safe moisture level that can be achieved by one of the effective processing techniques as solar drying. Drying is one of the oldest methods of preserving food. A solar dryer shortens the drying time by increasing temperatures and air currents. Fortunately, India is blessed with abundant source of solar radiation. This paper addresses the experimental performances of a Mixed-Mode Solar Drying System with Internal Reflectors for drying of Fruits, Vegetables, Spices and Medicinal plants. The mixed-mode solar cabinet dryer with forced circulation and internal reflectors has been developed and evaluated for its performance for drying of agricultural foods. Two 6 W DC fans powered by PV modules were used to ventilate the dryer. The cabinet solar dryer is 0.7 m in length and 0.7 m wide. Food products were cut into slices and loaded in wire mesh tray into the cabinet. Finally, this paper deals with a suitable design of a solar agricultural dryer that can be built in rural area with locally available construction materials and skills and retains the desired food quality.

Keywords: Cabinet solar dryer, Agriculture products, Solar radiation, Drying time, Drying rate

Introduction

It has been proved that moisture content from the agricultural food should be reduced to 10-20 % to prevent bacteria, yeast, mold and enzymes to prevent food spoilage. At the same time, the nutritional values, taste and flavour should be maintained. Drying is the traditional method to reduce the moisture content. It is the oldest preservation technique of agricultural food products and it is an energy intensive process. High prices and shortages of fossil fuels have increased the focus on using alternative renewable energy resources. Drying of agricultural food products using renewable energy such as solar energy is environmental friendly and has less environmental impact (Mühlbauer et al, 1986 and Zaman et al, 1989). The tropical and subtropical regions have abundant solar radiation. Hence the accessible option for drying would be the natural convection solar dryers. Many studies on natural convection solar drying of agricultural food products have been reported (Exell et al, 1980; Ekechukwu et al, 1999; Sharma et al, 1995; Bala et al, 1995 & Oosthuizen et al, 1995). The success achieved by indirect natural convection solar dryers has been limited, the drying rates achieved to date not having been very satisfactory (Oosthuizen et al, 1996). Furthermore, natural convection dryers are not suitable for small-scale industrial production of dried fruits, vegetables, spices and medicinal plants. These prompted researchers to develop forced convection solar dryers. These dryers are (1) solar tunnel drier (Bala et al, 2003), (2) indirect forced convection solar dryer (Mohanraj et al, 2009), (3) greenhouse-type solar dryer (Kaewkiew et al, 2012), (4) roof integrated solar dryer (Janjai et al, 2005), and (5) solar assisted dryer (Misha et al, 2016).

It is observed from the critical literature survey that temperature and air circulation over food during drying play a vital role in engineering design of solar dryer. The present study was undertaken to investigate the drying characteristics of various fruits, vegetables, spices and medicinal plants with a mixed-mode solar dying system with internal reflectors with air temperature and air velocity control.

Materials and methods

Drying equipment

The purpose of this work is to carry out a quality product output with the design of an energy efficient solar drying system. For this objective, the cabinet solar drying system provided with solar PV fans and internal reflectors was designed and manufactured.

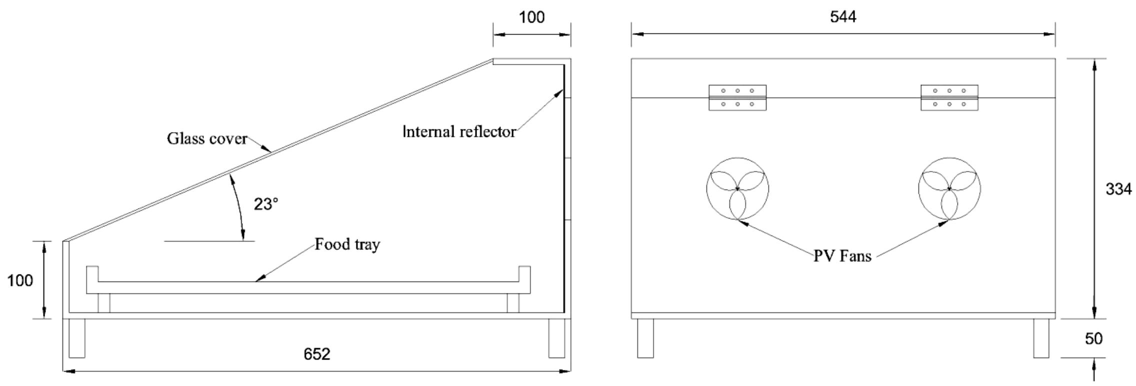

Figure 1: Schematic of proposed drying system

Solar radiation was allowed to pass through a transparent glass window located at the top of the cabinet, at south facing with a tilt equal to latitude to collect maximum solar radiation. The solar dryer has a cabinet made up of PVC foam board sheet with glass window on the top. Toughened glass of 4 mm thickness was used in glass window. The products to be dried are placed on wire mesh tray, placed within the cabinet. The inner surface of back vertical wall of cabinet is provided with reflective mirror sheet. The cabinet dryer is simple in construction. The ambient air enters from one of the hole kept at the backside of the cabinet and gets heated up with solar energy incident from the top window. Solar thermal energy is trapped in the cabinet and heats up the air and hence a green house effect is set into the cabinet. The hot air passes through the trays, carrying the moisture from the product. The forced circulation of air in the cabinet is achieved through the solar PV fan. There are two such fans provided in the cabinet dryer, one sucks the air while another discharges the air out of the cabinet. This arrangement sets the forced circulation of the air for attaining maximum moisture removal from the product. Table 1 shows the description of measuring instruments and equipments which were used in dryer.

Experimental setup

The air temperature (ambient and cabinet temperatures), relative humidity and solar radiation intensity were measured. PT-100 RTD sensors and SE20-D1 pyranometer with accuracy of 0.01 °C and 1% respectively, were used for temperature and solar radiation intensity. There are two temperature sensors and two humidity sensors were incorporated in the system, one measures the ambient air properties and other measures the cabinet air properties respectively. Weights of samples were measured every 60 minutes interval with a digital electronic balance with accuracy of 0.01 g and weight loss been recorded.

Drying experiment

The drying of the agricultural products depends on the temperature and humidity of the surroundings. Drying by traditional hot air under open sun, may prolong the drying time due to its intake of high humid air. But increasing the drying temperature seems necessary to shorten the drying time. On the other hand, the controlling temperature and rates of water removal is critical to gain optimal product quality during drying in solar dryer.

Fresh agriculture products of good quality from the same group of plants were procured from the local Market. Selection was based on visual evaluation of uniform color and geometry. The detail of solar drying system is shown in Figure 1. During each test, one kg agriculture products are washed, steamed and sliced. The sample was prepared in a hygienic procedure. Before inserting the samples into the dryer cabinet, the samples were weighted instantaneously. Weights of samples were measured every 60 minutes interval with a digital electronic balance and weight loss been recorded. The drying process was carried out from 9:00 am to 5:00 pm. The solar dryer was shut down at night. The drying action was continued until the required equilibrium moisture content was reached (no change was observed in mass). Furthermore, Solar PV fans were incorporated to the system to set the forced convection of hot air in the cabinet.

The experiments were conducted considering two cases:

Case 1: Cabinet dryer with natural convection
The air movement in the cabinet is simply generated by density gradients occurred due to absorption of solar radiation.

Case 2: Cabinet dryer with forced convection and internal reflectors
Along with Solar PV fans, internal reflector is placed at the inner side of cabinet dryer to reflect the solar rays falling on the sides of the cabinet.

The drying process was carried out from 9:00 am to 7:00 pm in the months of January to March 2016. The air temperature and relative humidity in and out of the solar dryer were measured. A temperature range of 14-33℃ outside the dryer and 50-63℃ inside the drying chamber with a corresponding relative humidity range of 32-39% outside and 24-42% in the drying chamber, were recorded during the drying process.

System analysis

Drying is basically a phenomenon of water removal by evaporation from a solid. Most part of the energy consumption during drying is for the evaporation of water in liquid phase into its vapor (2258 kJ/kg at 101.3 kPa). Moisture content in the product is expressed either on dry or wet basis. Moisture content in wet basis is given by:

$$M_{wb} = \frac{m_w}{m_w + m_d} \tag{1}$$

Similarly, moisture content in dry basis is given by:

$$M_{db} = \frac{m_w}{m_d} \tag{2}$$

The weight of the water that can be extracted by air flow from the products to be dried was defined as:

$$m_w = m_p \left(\frac{M_{wb,i} - M_{wb,f}}{100 - M_{wb,f}} \right) \tag{3}$$

Solar dryer efficiency is defined as the ratio of the energy required to evaporate moisture to the heat supplied to the dryer. It is a measure of the overall productiveness of a drying system. The heat supplied to the dryer is the solar radiation incident on the solar collector. The system drying efficiency can be obtained using the following equation:

$$\eta_d = \frac{m_w h_{fg}}{A_c I_{GT}} \tag{4}$$

The drying rate is a principal parameter to represent the rate of water removal from the sample food. The mathematical equation form of the drying rate is,

$$DR = \frac{M_{db,t+dt} - M_{db,t}}{dt} \tag{5}$$

where $M_{db,t+dt}$ is the moisture content (kg water per kg dry matter) while $t + dt$, and t is the drying time in minutes.

Experimental results and discussion

The food samples considered for drying were: Tomato, Potato, Cabbage, Ginger, Green chili and Mango. All the experiments were designed complete randomly in factorial. The data obtained were subjected to statistical analysis for analysis of variance using standard methods. Values were considered at 95% confidence level. All the experiments were performed in triplicate.

Comparison of the moisture contents of various foods in the solar cabinet dryer as per case 2 with those obtained by the system as per case 1 is shown in Fig. 3 to 8. The solar drying in case 1 required 1080 minutes to dry tomato samples from 92% to 9% as compared to 92% to 5% in 660 minutes in case 2 as shown in Fig. 3, while potatoes took 850 minutes in case 1 from 82% to 4.5 % and 680 minutes in case 2 from 82% to 4 % as shown in Fig. 4. Similarly, in cabbage, it is found as 480 minutes from 92% to 10% in case 1 and 300 minutes from 92% to 9.6% in case 2 which is clearly seen in Fig. 5. Fig. 6 shows that the Ginger took 840 minutes to dry from 89.1% to 10.1% in case 1 and 600 minutes from 89.3% to 10%. Green chili took more time for drying comparatively as shown in Fig. 7. It was found as 1560 minutes for drying from 78% to 20% in case 1 whereas in case 2, 1200 minutes were required for drying from 78% to 10%. In the last sample of mango, it was found 1260 minutes in case 1 and 1020 minutes in case 2 as shown in Fig. 8. The summary of various operational parameters and observed parameters during drying of above mentioned samples is tabulated in Table 1.

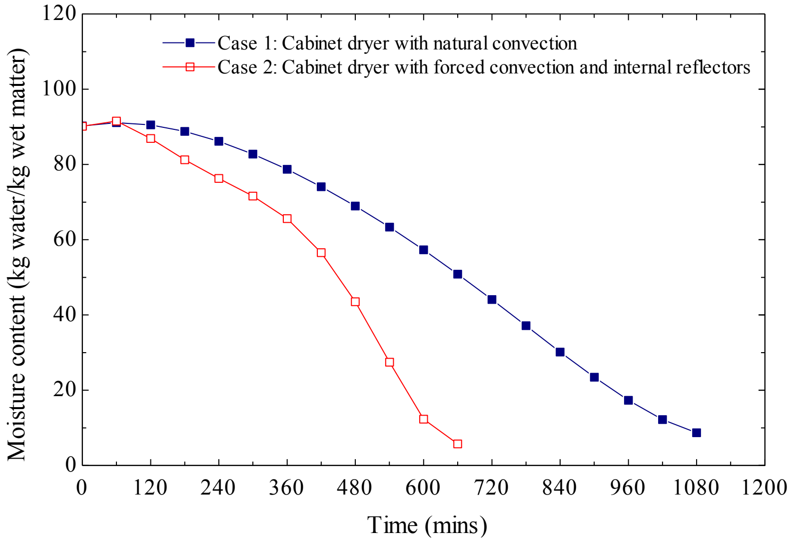

Figure 3: Variations of moisture content with time for a typical experimental run during solar drying of tomato

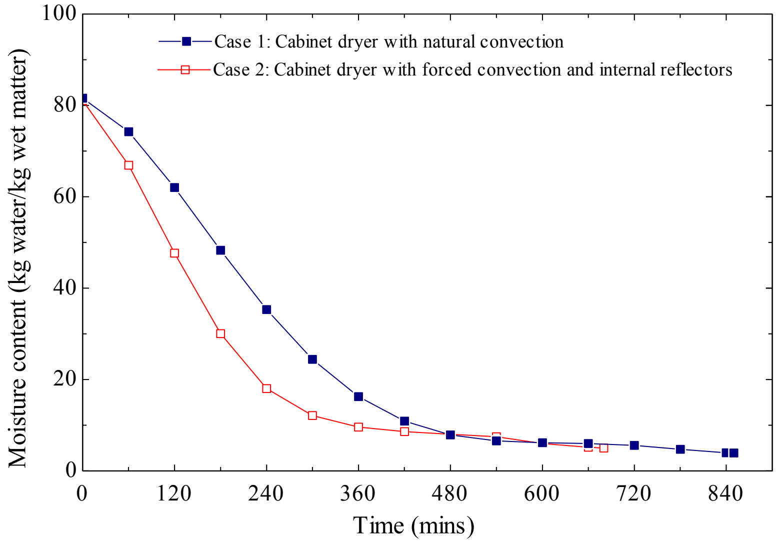

Figure 4: Variations of moisture content with time for a typical experimental run during solar drying of potato

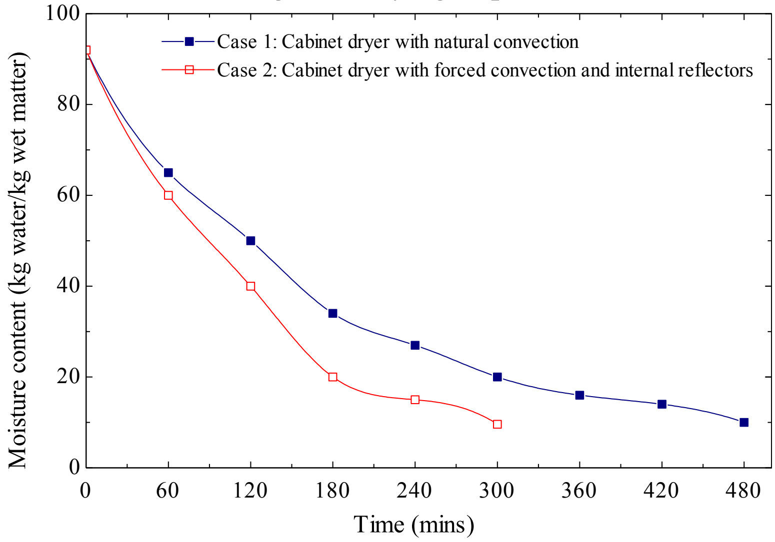

Figure 5: Variations of moisture content with time for a typical experimental run during solar drying of cabbage

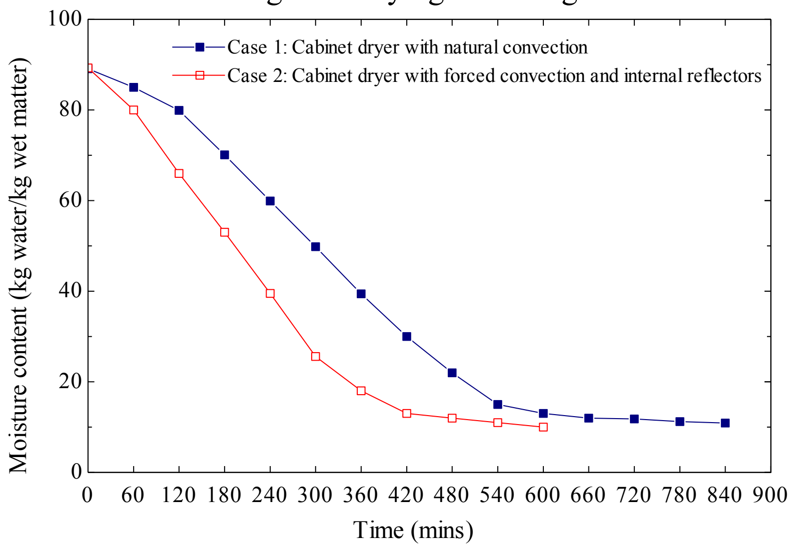

Figure 6: Variations of moisture content with time for a typical experimental run during solar drying of ginger

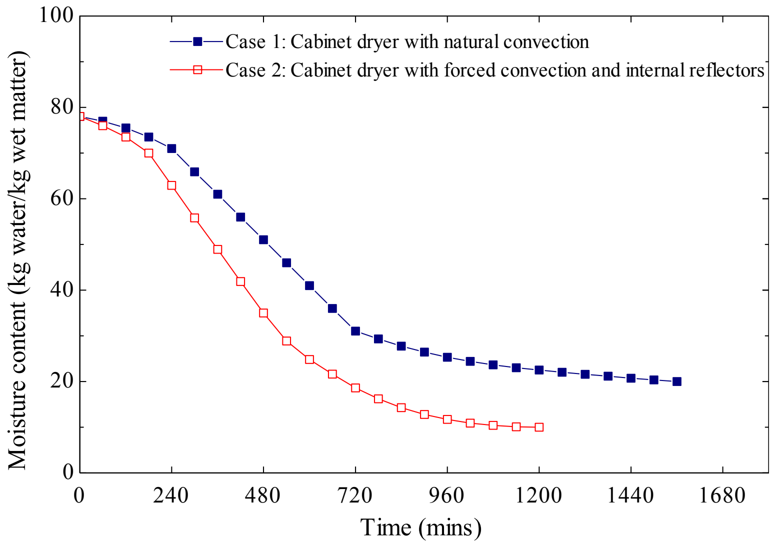

Figure 7: Variations of moisture content with time for a typical experimental run during solar drying of green chili

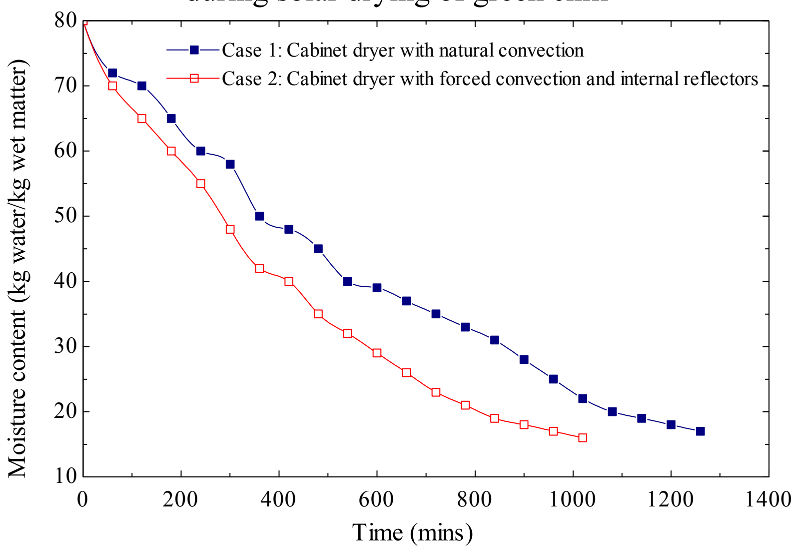

Figure 8: Variations of moisture content with time for a typical experimental run during solar drying of mango

Table 1: Summery of operational and observed parameters during drying of various food samples

Drying food	Ambient temperature Range (C)	Average Drying chamber temperature (C)	Average drying time		Time saving by Solar drier (%)
			Solar drying	Sun drying	
Tomato	14.1 - 25.6	50.1	1080	660	39
Potato	15.6 - 26.9	52.8	850	680	20
Cabbage	17.6 - 27.3	55.1	480	300	37.5
Ginger	17.7 – 28.2	57.8	840	600	28.6
Green chili	18.1 – 29.1	58.6	1560	1200	23
Mango	22.6 – 33.3	62.8	1260	1020	19

Conclusion

The dryer in the present study is easy to build and required only semi-skilled labor and limited manufacturing facilities to fabricate. Thus the dryer is most suitable for use in urban as well as rural areas of the country. It is found significant reduction in drying time with forced convection and internal reflectors. The farmers can dry vegetables and fruits when these are available in plenty and at low cost. Dried vegetables can be sold in the off season when prices of vegetables are high and farmers can generate more revenue. The use of the proposed solar dryer will be a great boon for farmers in the developing countries.

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